german & milne inc.

130 Slater Street, Suite 630
Ottawa, Ontario, Canada K1P 6E2
Telephone: (613) 230-6201 Telex: 053-4499 GERMIL OTT

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FLOW TRAJECTORIES ABOUT AN AIR CUSHION ICEBREAKING BOW

A Study for
TRANSPORTATION DEVELOPMENT CENTRE
TRANSPORT CANADA

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17. Abstract

Experience with the operation of the air cushion icebreaking bow (ACIB) and a study of available literature raised questions regarding the value of a notch in the planform of an ACIB to accommodate the bow of the host ship. Unsupported claims had been made for reduced resistance, but these seemed to be more than offset by proven difficulties. Model tests in ice to date had proved unsatisfactory, but it was thought that simple flow visualization might show whether strong lateral flow, sufficient to divet ice from impact with the ship, was actually present.

Model tests were carried out at the National Research Council of Canada, but nothing conclusive resulted. However, there was clear visual evidence that the ACIB had no noticeable effect on the lateral flow of water below its plenum.

Full-scale resistance tests with the Canadian Coast Guad ACIB, with and without a notch, are recommended, as well as a study of air cushion icebreaking modelling techniques.

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17. Abstract

L'expérience acquise dans l'exploitation d'une plate-forme brise-glace à coussin d'air (ACIB) et l'étude des traités d'hydrodynamique pertinents remettent en question l'utilité de l'échancrure prévue dans cette plate-forme pour accueillir la proue du navire pousseur. Les concepteurs de la plate-forme avaient mis de l'avant, pour justifier cette forme, une hypothétique réduction de traînée qui pourtant semblait déjà largement contrebalancée par une construction nettement plus complexe et plus fragile qui entraîne des coûts de réalisation et d'entretien plus élevés. Les essais sur modèle réduit réalisés jusqu'ici ont infirmé l'hypothèse d'une réduction de traînée, mais il restait à vérifier, par simple visualisation des écoulements, s'il se développait sous l'ensemble plate-forme/navire pousseur un écoulement latéral suffisamment fort pour empêcher les glaces brisées de heurter la coque du navire.

Des essais sur maquette ont été menés aux installations du Conseil national des recherches, mais les résultats n'en sont pas concluants. Par contre, la visualisation des écoulements a montré clairement que la plate-forme à coussin d'air n'au aucune influence notable sur l'écoulement latéral de l'eau sous le coussin.

Le rapport recommande que des essais en vraie grandeur soient menés avec la plate-forme brise-glace à coussin d'air d'abord dans sa forme originale puis sans l'échancrure remise en question. Il préconise aussi l'étude des techniques de modélisation des phénomènes de rupture des glaces par véhicule à coussin d'air.

18. Key Words	19. Distribution Statement
Brise-glace, proue brise-glace à coussin d'air, plate-forme à coussin d'air, essai sur maquette.	Le CDT dispose d'un nombre limité d'exemplaires.

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1.0 INTRODUCTION

1.1 Experience with the operation of the air cushion icebreaking bow (ACIB) and a subsequent literature search and study raised qestions concerning the value of a notch in the planform of an ACIB to accommodate the bow of the host ship. Numerous claims have been made with regard to reduction in resistance and improved ice clearance, but all were speculative and unsupported by hard data. On the other hand, the disadvantages introduced by the notch in the way of engineering complexity, increased capital and maintenance costs, and operational difficulties are well documented.

1.2 Model tests in ice to date have proved unsatisfactory, but is was thought that simple flow visualization might provide an indication of any advantageous characteristics in the flow pattern about the ACIB/ship bow combination, and that this might be done in the Flow Visualization Water Tunnel at the National Research Council Canada (NRCC). Preliminary tests conducted by courtesy of the Low Speed Aerodynamics Laboratory (Mr. R.J. Templin, Head) showed that the scale was too small for adequate control, although the results were not without interest.

1.3 After further investigation of available facilities, it was suggested that more satisfactory tests might be conducted in the High Discharge Flume in the Hydraulics Laboratory (Mr. J. Ploeg, Head). As a result, German & Milne Inc. was awarded a small contract to carry out a simple, qualitative study.

2.0 TESTS IN THE FLOW VISUALIZATION WATER TUNNEL

2.1 The Flow Visualization Water Tunnel, which has an interesting history, is described in Reference 1. It was designed and built in 1939 at the Aerodynamische Versuchsanstalt, Goettingen, Germany, and throughout World War II performed as a research facility for the German aircraft industry. After the war, it was shipped to Canada by the RCAF, and found a home in the Low Speed Aerodynamics Laboratory at NRC, where it was extensively modernized in 1960, and has been used to investigate many problems in fluid dynamics.

2.2 The water tunnel resembles a conventional closed circuit wind tunnel, is constructed of mild steel sheeting, and normally contains 350 gallons of water. A general view of the tunnel is shown in Figure 1. The working section, Figure 2, spans the gap between the 4 to 1 contraction and the return leg duct. Glass plates form the front and bottom sides.

2.3 The water level is normally well above the working section and separated from it by a removable glass roof. However, for the ACIB/ship bow model the level was lowered into the working section, and a false roof of plexiglass was installed to simulate an ice sheet. This roof also served to remove the slope in the water surface which would have been present otherwise.

2.4 A very simple model was constructed in plexiglass, consisting of a box to simulate the plenum of the ACIB, and a block of plexiglass cut to represent the bow of a ship. The bow was notched into the plenum, which was connected to an air supply. Plenum pressure was adjusted by attempting to match the plenum waterline closely to the bottom of the plexiglass ice sheet.

2.5 Attempts were made to observe the flow at low speeds, 2 - 3 knots full scale, but it proved impossible to achieve a situation sufficiently stable for any meaningful observation to be made. With the very small plenum volume and the dynamic situation, the pressure fluctuated and air bubbles of all sizes escaped in quite random directions. Some pictures showing this situation were taken through the bottom of the tank, Figures 3a, b, c and d. The ship bow in these pictures is notched almost to the leading edge of the plenum. It was intended to separate the ACIB and ship bow progressively until they were separated by a small gap.

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2.6 After some discussions it was decided to discontinue these tests in favour of tests at a larger scale.

2.7 The situation encountered in these tests does bear some similarity to the full scale case when the cushion pressure exceeds the ice thickness (water head) by an appreciable amount, and heaving is induced by the volume/pressure changes created by the escape of large bubbles. In the case of the model, which was not free to heave, an unstable pumping resulted.

3.0 TESTS IN THE HIGH DISCHARGE FLUME

3.1 The High Discharge Flume is described in Reference 2. The flume is 2.75 m wide, with walls 1.36 m high, and has a working section 10 m in length. For a flow depth of 1 m, adjustable by a sluice gate at the downstream end, the velocity is infinitely variable from 0 to 0.64 m/s by means of a variable pitch propeller pump (0 to 1 m^3/s) working in parallel with a fixed propeller pump (0.75 m^3/s). There are two viewing windows in one side.

3.2 It was decided to use 1/40 scale models for the tests, because the flume would accommodate an ACIB model and a 1/40 scale model of the R Class icebreaker, which was readily available. The velocity range available was equivalent to 0 to 4 m/s (7.8 knots at 1/40 scale). It was suggested that the models used in the DeHavilland/Arctec tests (References 7 and 11) might be used, but such models were judged to be too complex for the project.

3.3 Four ACIB models were constructed, as follows:

- Model A, representing a rectangular planform (see Figure 4)
- Model B, representing the current CCG ACIB
- Model C, representing a semi-eliptical planform
- Model D, representing a swept, arrow-head planform

All models had decks of 3/8 in plywood

In the case of Model A, the skirts were represented by a solid section cut from high density foam and fluted to provide a configuration resembling the gaps between the skirt segments. This model was not notched.

In the case of Models B, C, and D, the skirts were represented by a straight piece of galvanized sheet, scalloped at the bottom edge. These models were notched.

Cushion air was provided by a Shop-Vac blower, transferable between models, and connected to them by a short rigid tube with an adjustable air bleed. Pressure was measured and flow calculated, both being found adequate to meet the scaling requirements.

3.4 The models were suspended from beams laid across the top of the flume, so that they floated when the water was brought up to level (see Figure 5).

3.5 It had been expected that the water in the flume would be clear, but, in the event, it turned out to be very dirty, and it was difficult to see dye streams, even after a floodlight had been rigged on the bottom of the flume to shine upwards at the models. This situation seriously affected the project, because video and photographic recording was virtually impossible, and small streaks of dye were very difficult to see.

3.6 It was proposed at this point to abandon the project, but, after discussion with the Scientific Authority, it was decided that, having done all the preparatory work, some tests should be attempted. These were all done with Model A, which performed very realistically, and could be trimmed quite easily by moving ballast blocks about on its deck.

3.7 It was found that the lower velocities, much below 0.5 m/s, could not be used because the concentration of dye required diffused too much over the distance of interest. A full scale flow rate of 118 m^3/s was assumed, so the model flow rate was taken to be 0.01 m^3/s, which was within the capacity of the blower (calculated from dynamic pressure measurements at the intake).

3.8 Several tests were made with the ACIB/ship combination at different separations, but no significant change in the flow pattern was observed. There was no noticeable outflow along the sides of the ACIB, and it was observed from above that the streamlines ran straight through without any deflection. Viewed from the side window, the streamlines were deflected downwards at the bow, flowed parallel to the surface under the model, and rose again at the stern. The outflow, which Milano (Reference 6) predicted, did not occur in any of the tests. The flow around the bow of the ship did not appear to change at all between tests, including one run without the ACIB, and followed a pattern which appeared entirely appropriate to the icebreaking lines of the R Class ship.

3.9 It was then decided to remove the ship model from the tank and run a few tests with the model at different angles to the flow. There was no change, and even at 45°, when it had been expected that some disturbance wuld occur at the outboard corners, the flow pattern remained the same. There was no discernable wave pattern (see Figure 6).

3.10 It had been suggested that floating pieces of ice in the flume might give an indication of the action of the ACIB on broken ice. However this was not considered to be likely, because the model skirts were rigid and probably would not ride over floating objects. In practice this is exactly what happened; the ice stopped at the bow of the model.

3.11 From the beginning it had not been expected that anything would be obtained from these tests other than an indication of the pattern and influence of the flow of water past the ACIB and around the bow of the host ship. Although it was not expected that the pressure wave from the ship would be significant at icebreaking speeds, it was presumed that some indication of the effect of the cross flow velocity claimed by Milano would be noticeable. In the event, no such effect was detected.

4.0 DISCUSSION

4.1 As has been mentioned, the project was preceded by a literature search and a study of the material obtained. Since the tests have proved of little value, except possibly to confirm what would have been expected intuitively - that the ACIB has virtually no effect on the horizontal flow pattern - a summary of pertinent quotations is presented below with appropriate comment.

4.2 A few facts about the circumstances of air cushion icebreaking must be stated first in order to provide an understanding of the factors involved in any argument concerning the value of a notch. These facts are derived from full scale experience to date.

4.2.1 In low speed air cushion icebreaking, the ice is made to break as a cantilever under its own weight by equalizing the pressure above and below the ice sheet as it enters the plenum of the ACIB. To achieve this, the cushion pressure must be equal to or greater than the water pressure at the bottom of the ice sheet.

4.2.2 The water under the plenum is agitated violently by falling and jostling ice slabs, which cover most of its surface. The movement of air in the plennum is at low velocity, except directly under the fan outlets (CCG ACIB) and at the bottom of the skirt segments.

4.2.3 With the Canadian Coast Guard ACIB, ice up to 91 cm (36 in) has been broken, and a speed of 3.34 m/s (6.5 kn) achieved in 50 cm (20 in) of ice. Typically the major dimension of the slabs varied from about 1.5 m to 3.5 m, and $5m^2$ may be taken as reasonable for a 50 cm thick slab. The mass of such a slab would be 2305 kg (2.27 tons). The maximum length of the cushion footprint of the ACIB is about 22m, which means that any clearing force would have, say, 7 to 15s to act on this mass - and the masses of the other slabs with which it is in contact. Evidently the ice is unlikely to be moved laterally until it strikes the bow of the host ship.

4.2.4 The notch of the CCG ACIB is about 7m deep, but this is very misleading because the bow of its usual host ship, the CCGS ALEXANDER HENRY, is raked and flared. This means that only a small length of the bow is actually in

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the depressed water area at the stern of the ACIB (see Figure 7, which is drawn to scale). Consequently there is no possibility of shouldering broken ice under the ice sheet or avoiding the tilting and stacking of ice blocks along the side of the ship. Even to have a chance of doing this, the effective notch would have to extend aft to the maximum beam of the ship, and, at that, the possibility of shouldering the jumbled ice slabs aside and under the sheet seems somewhat optimistic, even if the daunting engineering problems were overcome.

4.3 During model testing ice was not being broken, and the flow of water under the ACIB and around the ship was steady and undisturbed. However, turbulent or not, it would appear that the influence of the ACIB on clearing, rather than breaking ice will be negligible, especially considering the inertia of the ice blocks involved. Furthermore, it is probable that the outflow of air is likely to have even less effect on the flow of water under an ACIB when it is icebreaking, because the surface of the water under the craft will be covered with ice slabs.

4.4 This is completely at variance with the conclusions to be found in Reference 6 on the flow field under the ACIB. It is believed that the magnitude and influence of the cross flow velocity has been exaggerated, and the observed sideways movement of ice from under the ACIB was caused by the ship's hull, which displaces all the water and ice through which it moves.

4.5 It is interesting to note that Reference 5 states that "the length (depth) of the notch is not overly significant and may be chosen more to optimize other necessary parameters such as structural details and/or skirt design details."

4.6 Reference 3 relates the notch to the "pushing arrangement between ship and bow platform," and there is note of "a study by Arctic Systems Ltd....to investigate alternative pushing concepts that could be used between the ship and the air cushion bow platform, both in the notched and unnotched configuration." Reference 4 reports that model tests to "establish whether the resistance reducing capability of an air cushion vehicle fitting snugly around the bow of the pushing vessel . . . is materially better than that of one pushed ahead" were unsuccessful, and "in some cases, the resistance (in ice) was higher

for the (notched) combination than for the HENRY alone". In further reference to the ACT 100 (Iceater 1), Reference 5 states, "In considering its attachment to the icebreaker "Alexander Henry", one of the basic questions which we had hoped to resolve by model testing was the necessity and benefit to icebreaking performance, of a "V" notch being introduced into the stern of the platform. As mentioned earlier, unfortunately the model tests were not conclusive on this point and a decision was taken, largely on the basis of operational considerations, to proceed with this structural modification. It proved to be an extremely costly feature and the associated problems of skirt modification and installation taxed the ingenuity of the shipyard personnel to the utmost." Reference 3 states that "the notch configuration and the simple 'butterboard' type pushing arrangement between the ship and the bow platform functioned well, and on the basis of qualitative observations, the notch arrangement was the major reason for the ship being able to successfully manoeuver the platform". No credit is given to the notch arrangement for the broken track cleared by the combination of ACIB and ship being "significantly wider, straighter and clearer".

4.7 The model tests reported in Reference 7 indicate quite clearly that an ACIB breaks ice, but does not clear it. This is also the case in the tests reported in Reference 11. A plow for ice clearing was fitted under the ACIB and tested during the latter series.

4.8 Reference 7 notes that "the decision to introduce the 'vee' notch into the stern of the ACT-100 was based largely on anticipated operational considerations for the ACIB/ship combination. Data from model tests was inconclusive as to the benefit of this feature in icebreaking performance. The modifications proved to be unexpectedly costly". It also states that "the questions of the the need for a notch, the depth of the notch and the interaction of the two vessels were not conclusively resolved. However, the notch made a convenient docking arrangement for the host bow". And, "the configuration of the notch in the craft makes it impracticable to accommodate all host bow configurations. However, this can be adequately alleviated by designing, fabricating and placing adaptor brackets in the notch".

4.9 In spite of the need not having been resolved during the ACT-100 trials, and the cost of providing a notch demonstrated to be very high, the CCG requirements for the Hoverlift Systems (HSL) design "were that each of the specified ships' bows be inserted into a notch in the platform . . . and that the platform cushion pressure be extended up to, and bounded by, the ship's side" (Reference 8). The patented HSL arrangement, designed to provide an effective seal in the notch area when coupled with seven specified host ships, proved to be unsatisfactory, and References 9 and 10 indicate clearly how much additional work (time and cost) had to be expended before the notch could be made to work at all for only one ship. Even then, further modifications were required to achieve proper inflation and reasonably simple handling.

4.10 It is interesting to note that during the model tests reported in Reference 12, dye streams were observed to flow straight through an AC barge as though it was not there, regardless of orientation (yaw angle). This model, which had flexible skirts, was tested in the same High Discharge Flume as the models reported on earlier, but it had a transparent plastic deck through which the dye streams could be followed without interruption. Also, for these tests the water was crystal clear.

4.11 In tests with the HL-301/LA PRAIRIE combination in 1978 and 1979, it was found that in thick ice (60 cm plus) at an unknown cushion pressure, and in thinner ice (35 - 50 cm) at 45 cm cushion pressure, the combination was frequently brought to a halt. It is claimed that this would not have happened if the HL-301 had been designed with a notch. However, it is interesting to note that during the 1983/84 operations at Thunder Bay, the ACIB/ALEXANDER HENRY combination, which does have a notch, was also brought to a halt on more than one occasion. This was due to the cushion pressure being inadequate for the ice condition encountered, and resulted in the ice passing unbroken through the ACIB until it reached the bow of the ship. Since the ship alone was incapable of breaking ice of that thickness, it stopped. The same thing could well have happened to the HL-301/LA PRAIRIE combination with a cushion pressure of 45 cm and in 50 cm of ice, especially in areas with snow cover. It seems likely that the same situation could have occurred in the 60 cm plus.

4.12 Operations with the Canadian Coast Guard ACIB during the 1982/83 and 1983/84 seasons have demonstrated the vulnerability to damage of skirt segments adjacent to the ship's bow in a notch. Apart from damage incurred in notching, they also suffer from damage caused by ice pieces being turned on edge by the parting action of the flared ship's bow, while they are still in the skirt/spray apron area (refer to Figure 7). This effect is particularly marked at higher speeds, when pieces can be seen to emerge with up to 50% of their volume protruding above the waterline. Without a notch the ice would pass straight through the plenum and emerge flat. The notch is unquestionably a high damage area by the very nature of its operation and geometry.

5.0 CONCLUSIONS

5.1 The ACIB obtains its buoyancy by displacing water under its hull, the surface of the water being depressed to a depth roughly equivalent to the cushion pressure head. Air escapes more or less uniformly around the periphery of the craft from under the skirts.

5.2 If the ACIB is pushed into an ice sheet, and the pressure head is equal to or greater than the water pressure at the bottom surface of the ice, a bubble of air will be forced under the ice, and, as the ice enters the plenum, the pressure above and below the sheet will be equalized. Since it is no longer supported by the water, the ice will fail as a cantilever under its own weight when a critical length has been reached.

5.3 The broken ice drops into the water and passes aft under the rear of the ACIB, at which point it floats back up to the undepressed water surface. At no point is it deflected unless by contact between ice pieces or with the structure of the ACIB.

5.4 THE ACIB is an icebreaking accessory, and, unless fitted with a plow or similar device, it does not clear ice.

5.5 The host ship clears the ice, by the mere fact of its presence, and there will be resistance to this clearing action from the unbroken sides of the ice sheet, unless the broken ice can be pushed underneath. This will be achieved only if the broken ice can be kept below the level of the bottom of the ice sheet, that is floating in the depressed water under the ACIB until it is up to or past the widest part of the ship. This would require the ACIB to be extended for a considerable distance along the sides of the host ship, unless the ship was provided with a short, reaming bow. Even so it does not follow that ice would be cleared under the sheet, because the ACIB breaks ice irregularly and the track width can vary considerably. An arrangement such as the Wass bow is required if clearing is a real requirement. This bow cuts a clean track, breaks the ice, and deflects it sideways under the sheet. However, it is an integral part of the hull of the ship, not an accessory, and the ice will be drawn back in behind the ship just like any other icebreaker, if some critical speed is exceeded.

5.6 In order to push an ACIB ahead of a ship, it is necessary to provide a connecting mechanism which will restrain the ACIB in yaw, permit limited freedom in roll and pitch, and allow it to heave between off cushion and full hover heights. This can be achieved by means of a 'butter-board', or similar device, and cables, as described in Reference 3. It is desirable to push in line with the centreline of the ACIB, as well in line with or below the centre of pitch rotation. Also less restraint will be required if the contact point is close to or forward of the centre of rotation in yaw, and this seems to be the origin of the requirement for a notch.

5.7 However, the notch on the ACT-100 was very shallow, and the notch on the ACIB is very complicated. Both were very costly, and that on the ACIB has introduced a necessity for trim tanks, complicated handling and increased maintenance. In either case, the craft might have been pushed from a point outboard, with the addition of some extra structure.

5.8 On both, the importance of a good seal between the notch sides and the ship's bow is emphasized. However, the real requirement is to reduce spray in that area, and to avoid air leaks. It is considered that the development of a spray apron with a top flap has now reduced the spray problem to an acceptable level, and a gap between the notch sides and the ship could probably be tolerated, particularly with some kind of inflatable seal/rubbing strip in the gap.

5.9 In References 8 and 11, it is noted that the wave drag will be influenced by the separation between the ACIB and the host ship, and David Dickins, of David Dickins Associates, says that he has proprietory information showing that the resistance of the ACT-100 was lower in its notched configuration. However, no figures are available, but it is doubtful whether any gain could be significant at low-speed icebreaking velocities.

5.10 In general, it is considered that the requirement for a notch has not been substantiated. However, it is clear that this will not be accepted universally until acceptable comparative resistance measurements have been made.

5.11 It is unlikely that further flow visualization tests would be of any value. However, should a better record of the flow pattern be required, this might be done at some future date immediately after the High Discharge Flume has been cleaned and refilled.

5.12 It is clear that quantitative testing is required in order to obtain resistance figures for a number of ACIB/ship separations, including notching. It should be appreciated that the interaction will be unique to a particular ACIB/ship combination, and one might expect the gain to be greatest for an icebreaking bow, which is designed to apply a downward force and, when notched, be able to take advantage of the downward deflection of the water already applied by the ACIB. A ship with a sheer bow, which is probably much better for ice clearing and general use with an ACIB, is not likely to obtain any such benefit.

5.13 The notch question must be resolved if any future designs for ACIB are to be accepted without any reservations. No matter how logical any arguments, pro or con, may seem to the proponent, only measurements are going to decide the issue.

6.0 RECOMMENDATIONS

6.1 It is recommended that tests should be carried out to establish the magnitude of resistance changes related to the notching and separation of the ACIB/ship combination.

6.2 Model tests previously conducted were inconclusive, and it is recommended that testing should be done at full scale using the CCG ACIB in combination with the CCG ALEXANDER HENRY (icebreaking bow) and tug THUNDER CAPE (sheer bow). The CCG ACIB is ideal for these tests because it can be pushed at different notch depths or with the notch closed.

6.3 It is recommended that the tests be conducted in two series, first over water, and then over ice. The overwater tests should be conducted to obtain resistances at icebreaking speeds, as well as open water transit speeds.

6.4 If bollard pull tests could be conducted at the same time, it would be extremely useful in the assessment of powering.

6.5 If is also recommended that study should be carried out with the aim of recommending a program for the model testing of air cushion vehicles and ACIB in ice. This program must be designed to permit comparison with theory and with full scale tests of the same configurations.

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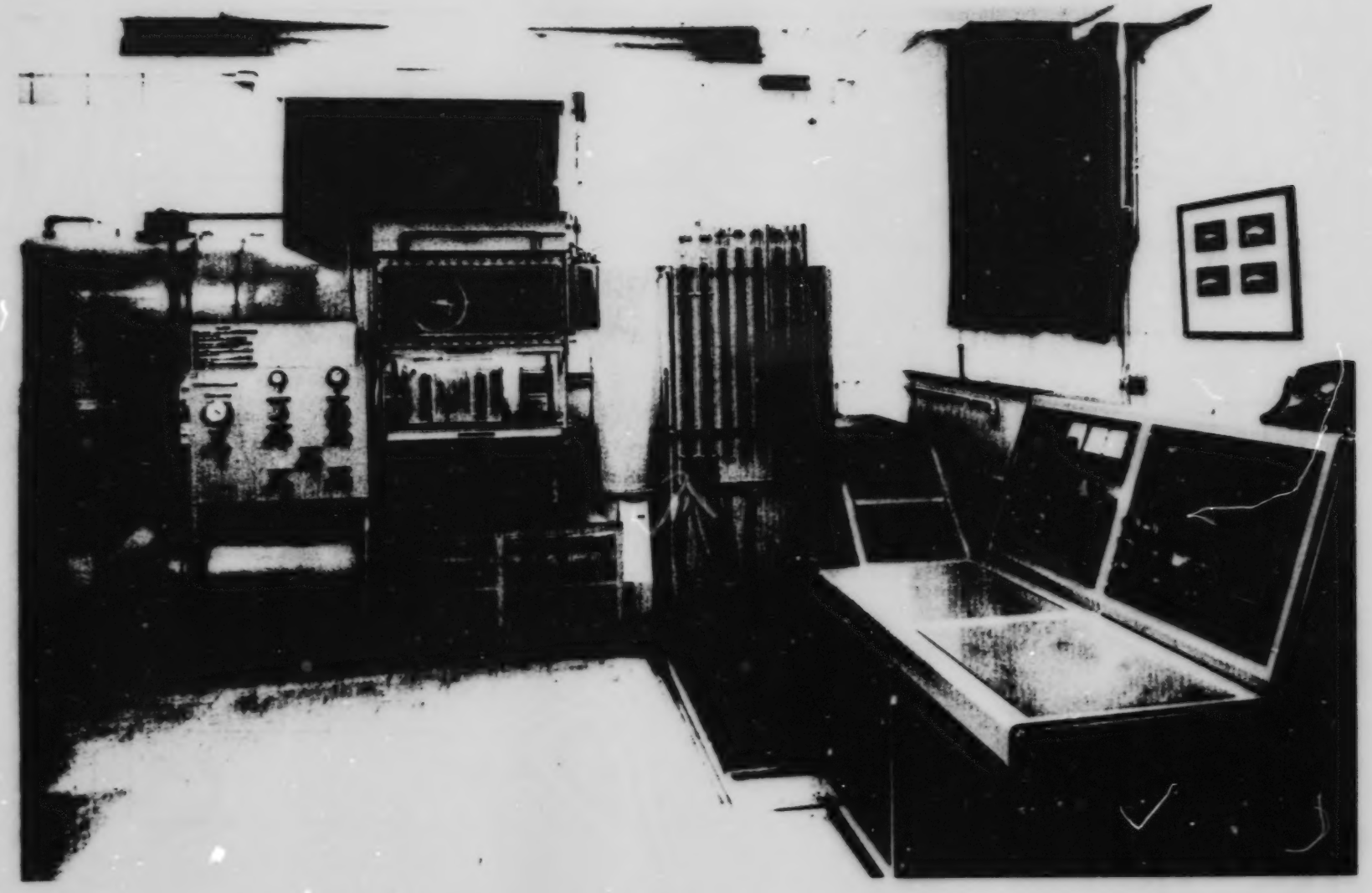

FIG. 1: GENERAL VIEW OF THE WATER TUNNEL

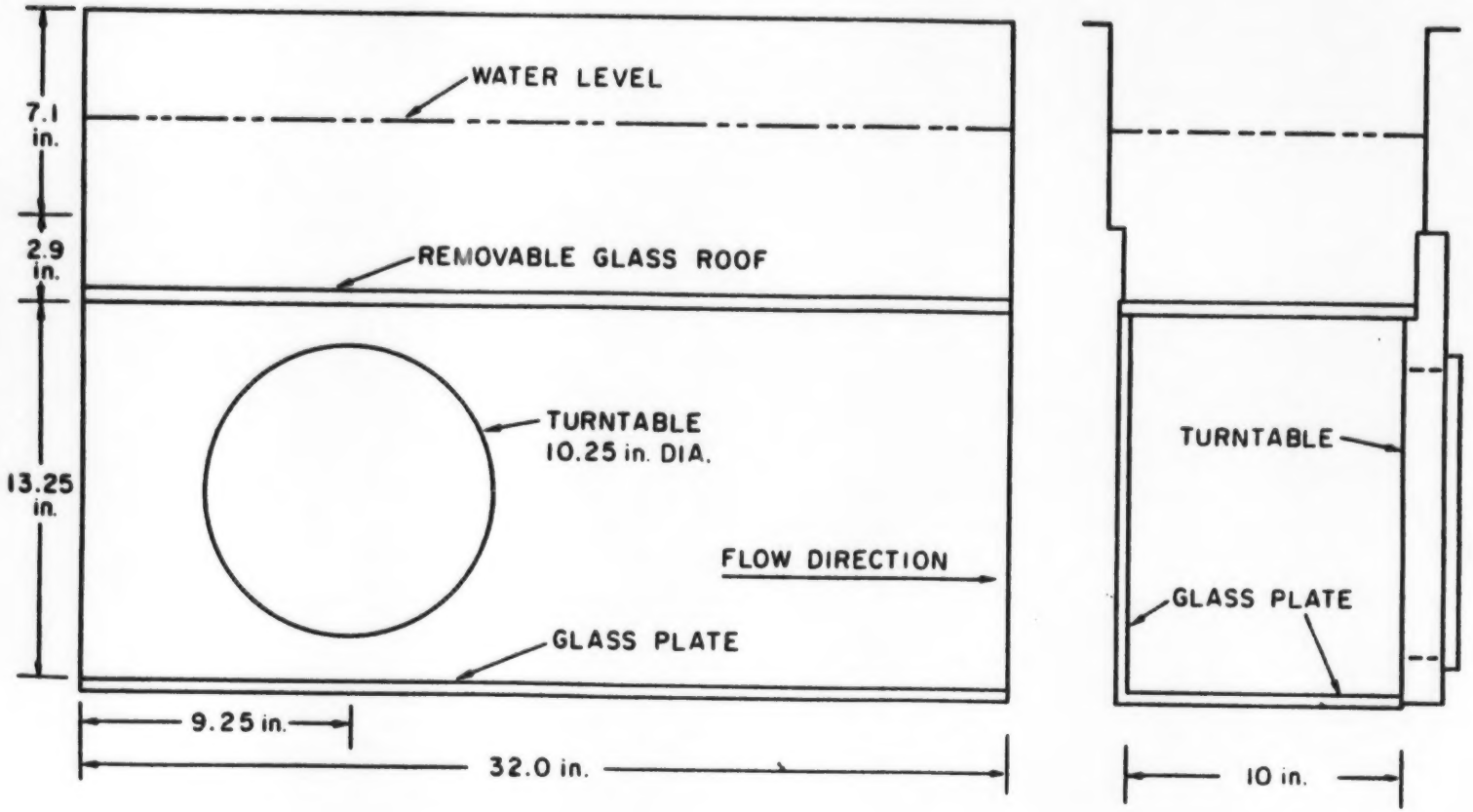

FIG. 2: WORKING SECTION

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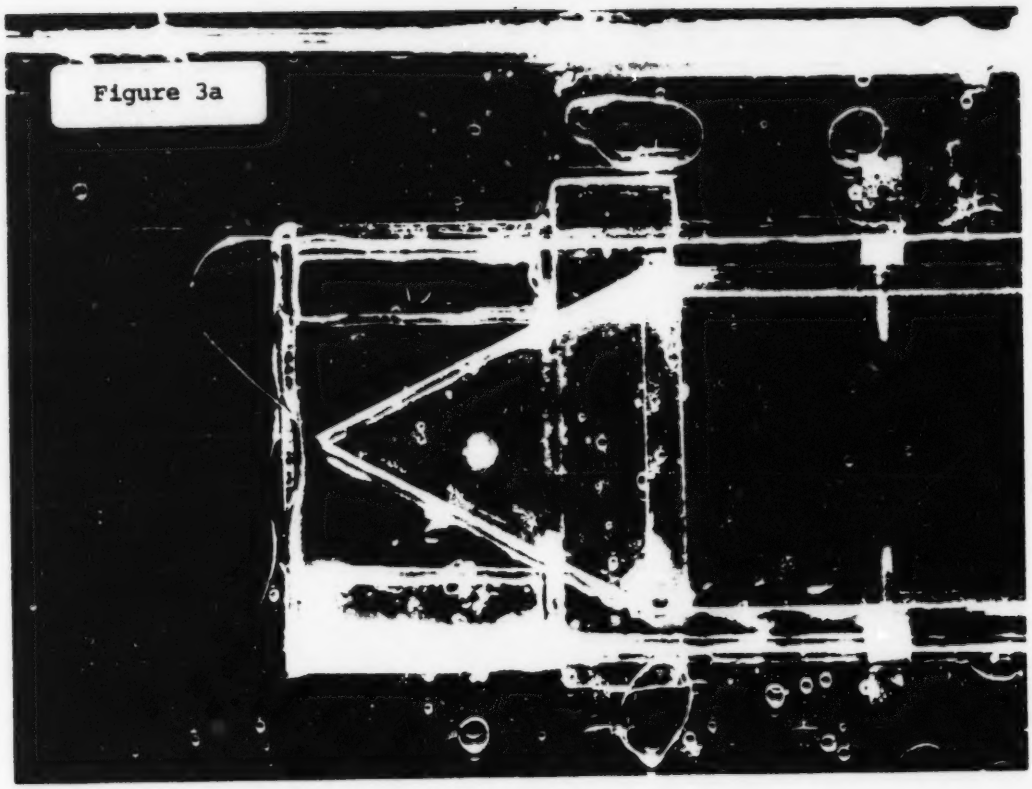
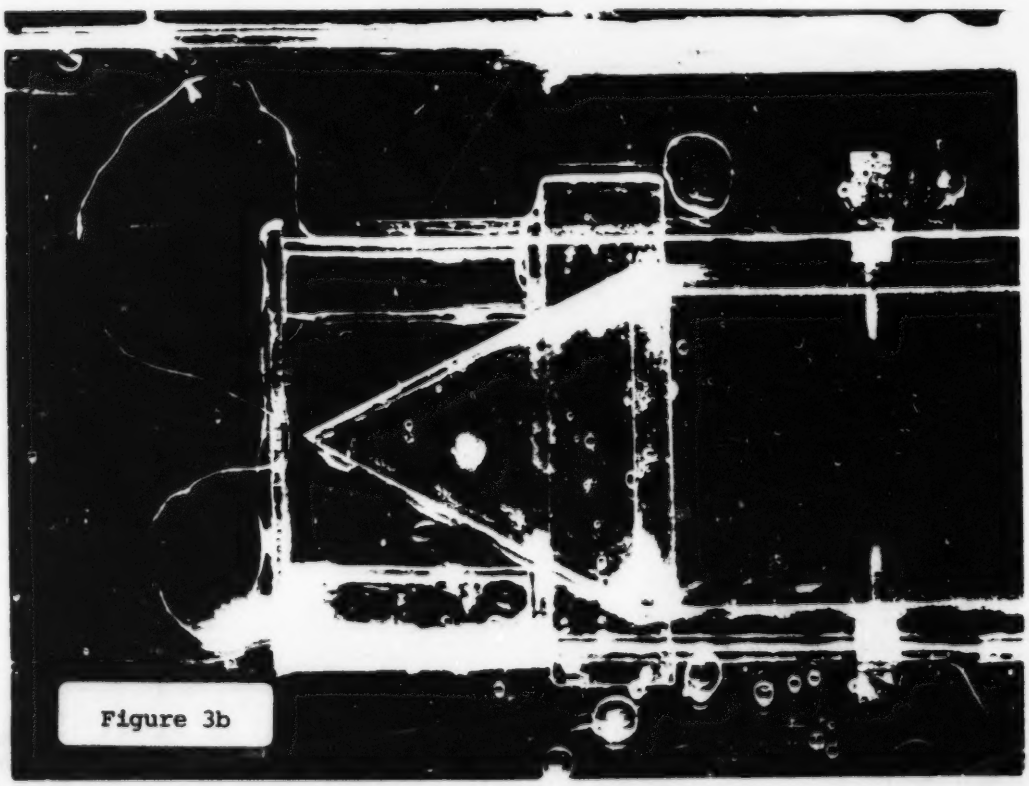
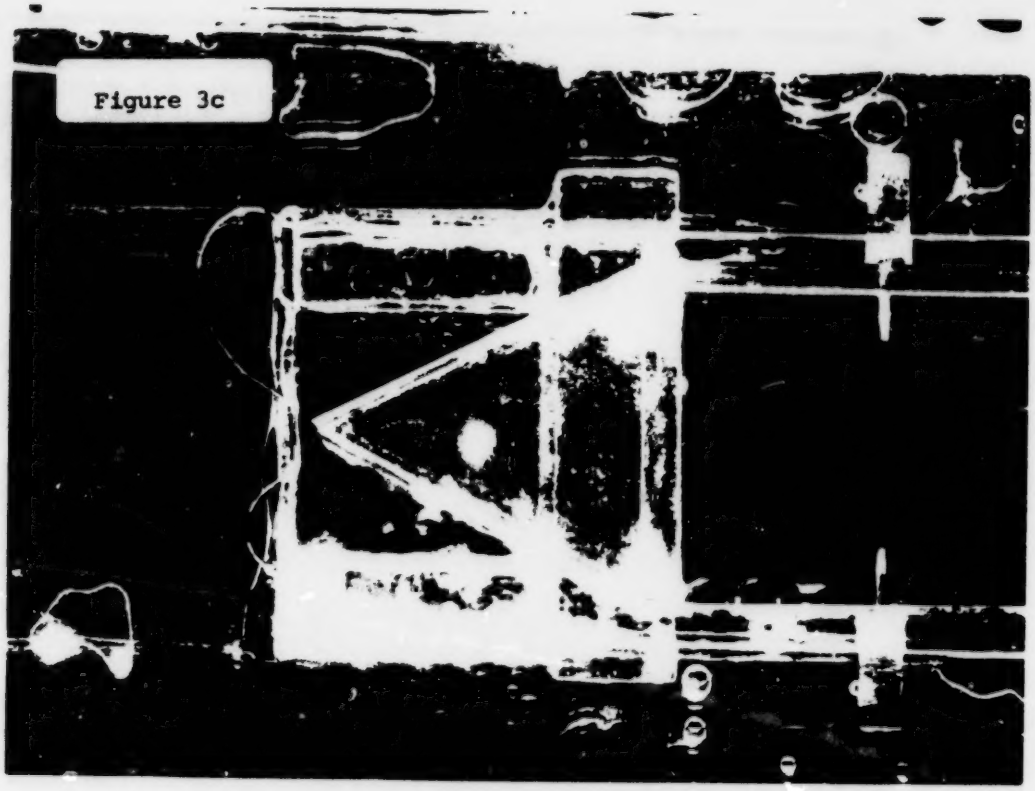


ACIB/Ship Model in Water Tunnel





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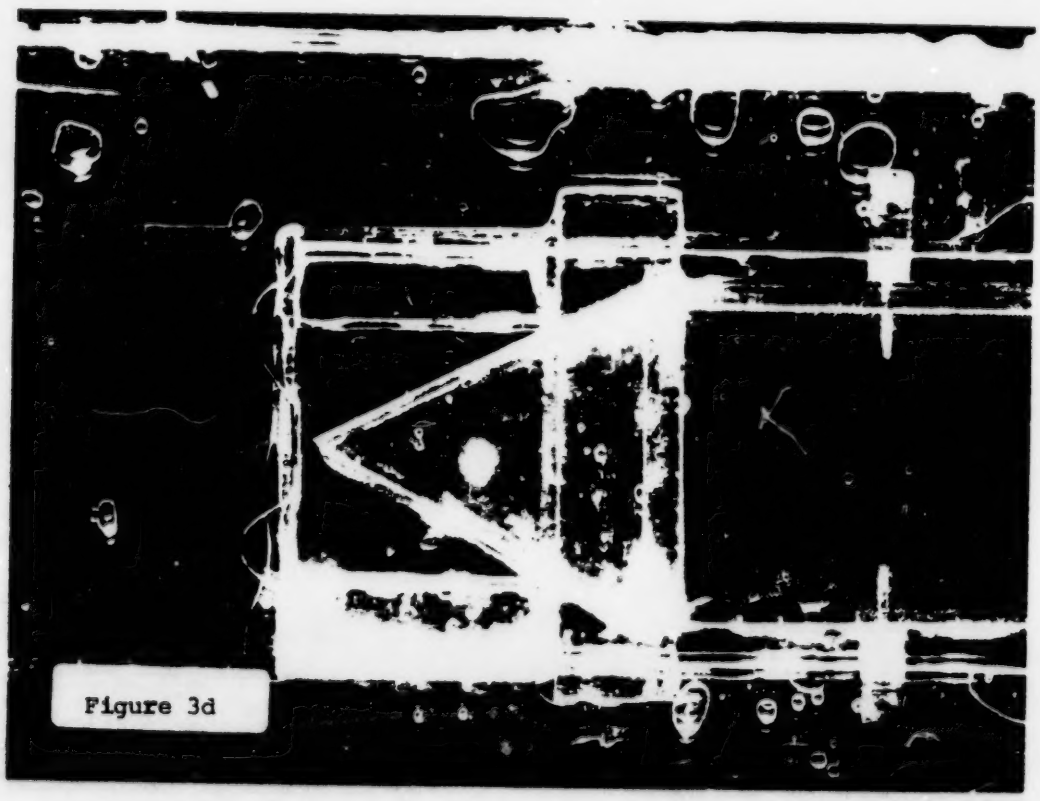

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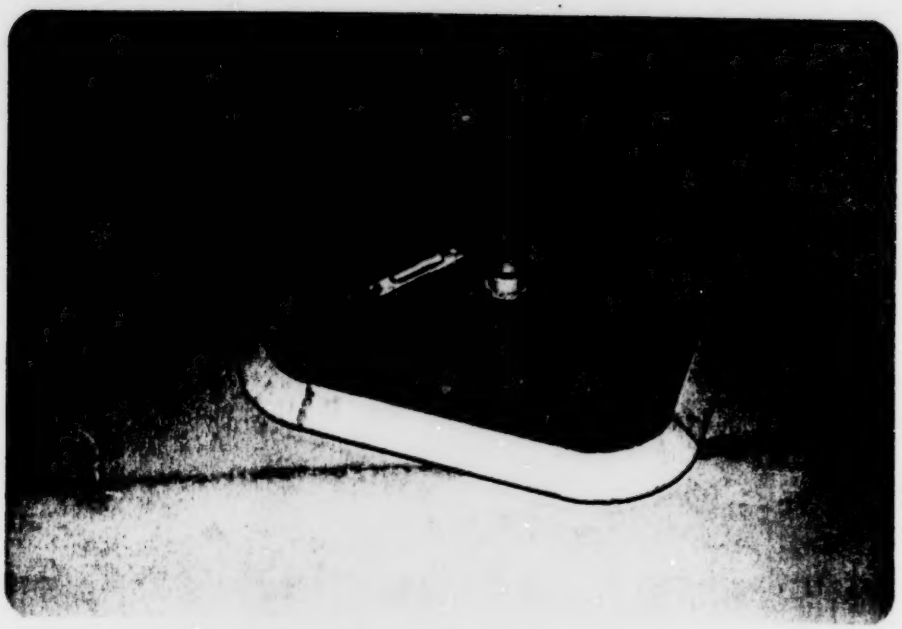

Figure 4A Model A, Top

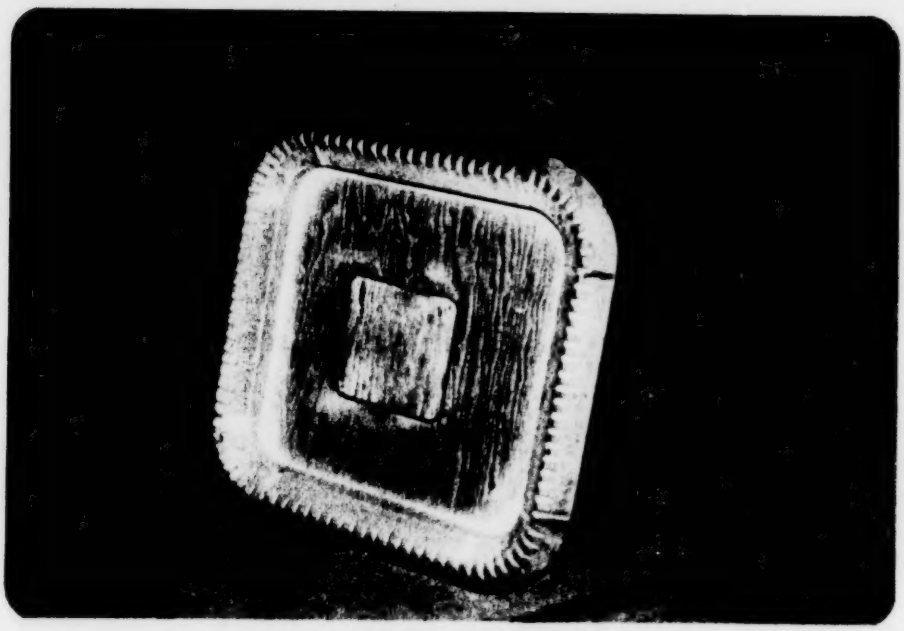

Figure 4B Model A, Bottom

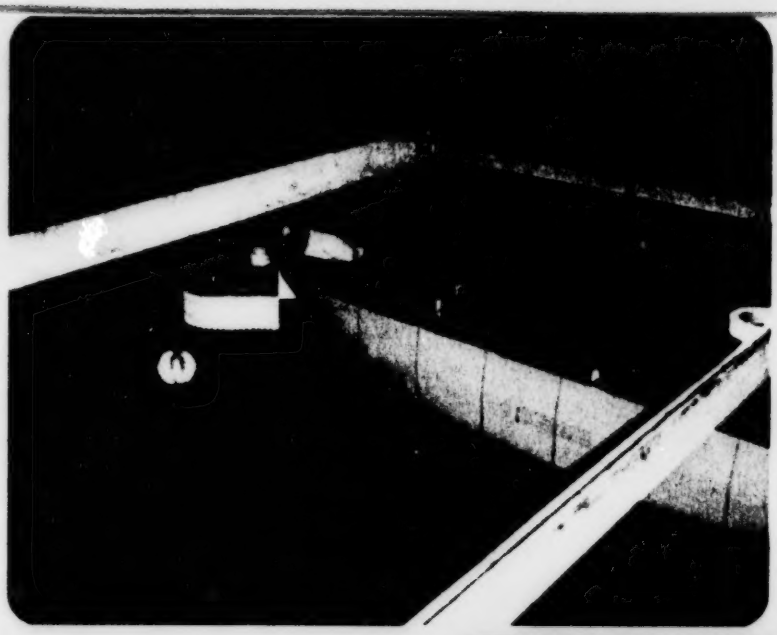

Figure 5a Model B and R Class Ship

Figure 5
ACTB Test Arrangements in High Discharge Flume

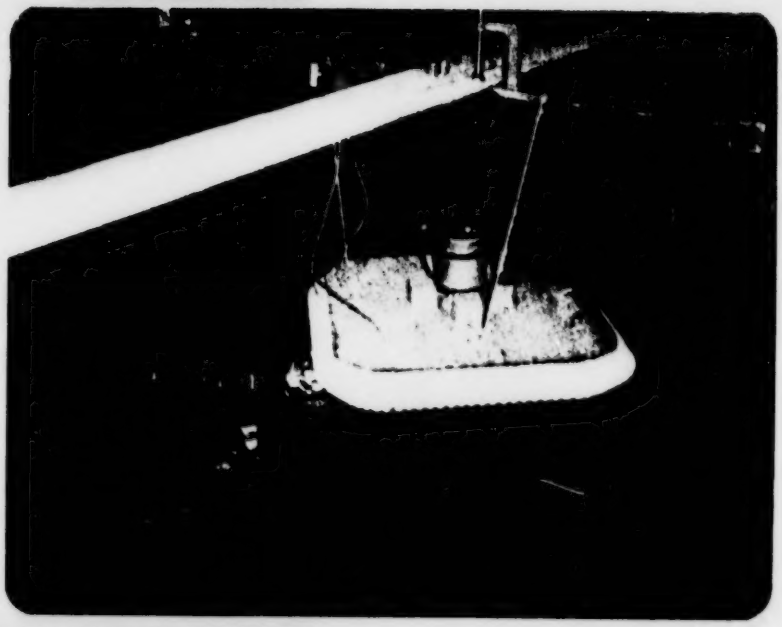

Figure 5b Model A

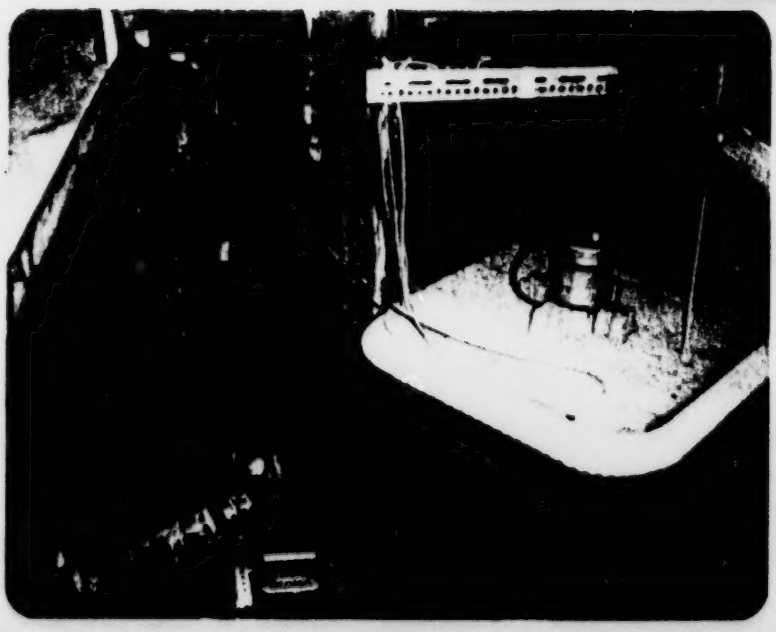

Figure 5c Model A

Figure 6 Dye Streams under Model A

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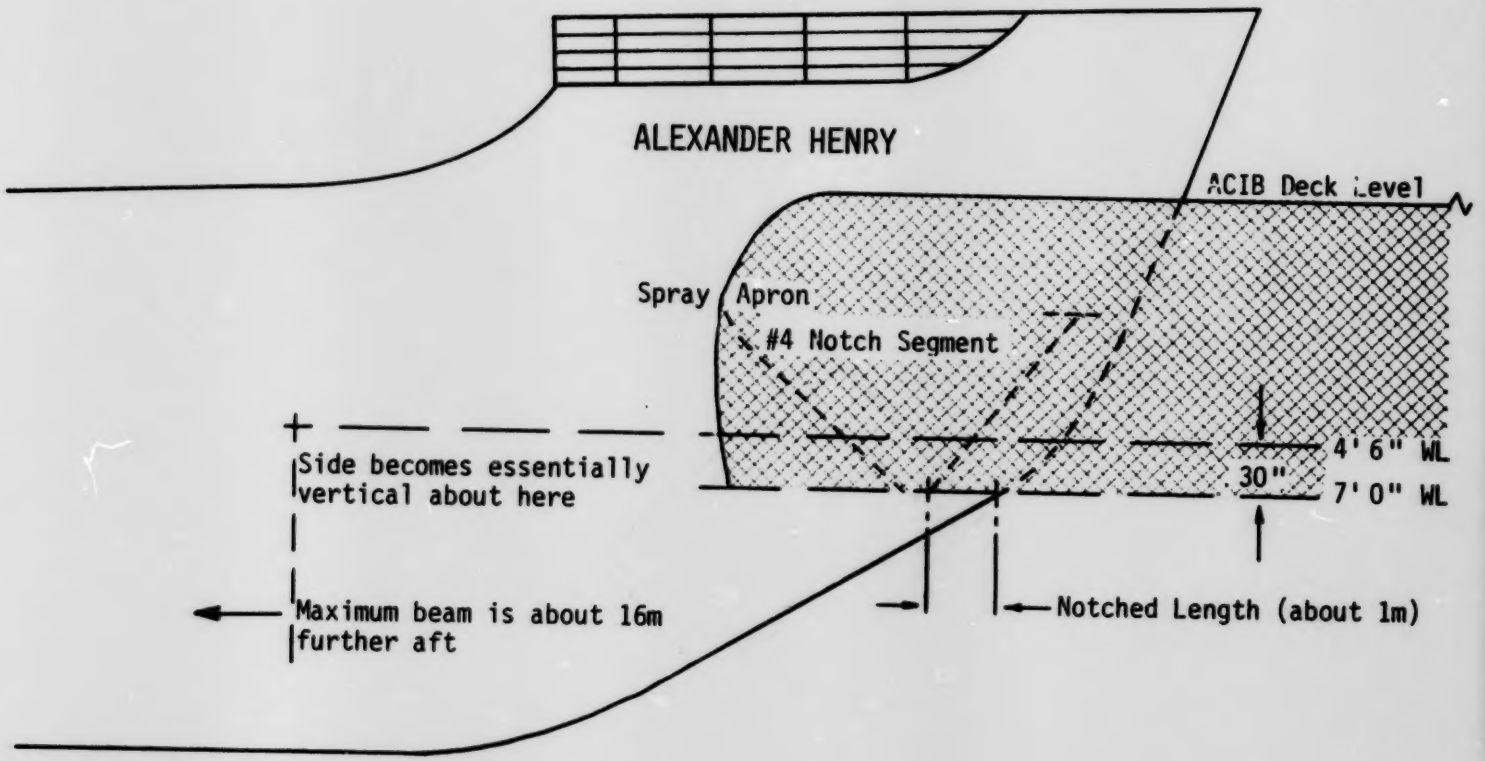

FIGURE 7 - SKETCH TO SHOW ACIB / ALEXANDER HENRY COMBINATION GEOMETRY